Limited energy supply, sunspots, and monetary policy

IMF/Norges Bank/IMFER-Oslo

Nils Gornemann[1], Sebastian Hildebrand[2] and Keith Kuester[3]

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[1]Board of Governors of the Federal Reserve System [2]University of Bonn [3]University of Bonn, CEPR, ECONtribute

The views expressed herein are the authors'. They do not necessarily reflect the views of the Board of Governors or the Federal Reserve System.

Motivation

Europe has seen a monumental change in the external environment

- shortages of imported goods, energy most recently
- volatile import/energy prices

Should this affect the way we think about monetary policy?

Active or passive response?

What we do

- provide conditions under which self-fulfilling fluctuations could arise from supply constraints on an input factor (here: energy)
- how can monetary policy can prevent those fluctuations?

- pencil-and-paper
- calibrated model

New Keynesian small open economy

Blanchard/Galí (2009) meets Bilbiie (2021)

- heterogeneous households (two-types) consume goods and energy
- produce goods using labor and energy, nominal rigidities
- energy either owned domestically or imported from Foreign

We deviate as regards the energy environment

- inelastic supply of energy
- energy price moves flexibly to clear the domestic market for energy

Energy-price-economic-activity feedback loop – closed economy

Suppose non-fundamental beliefs of high energy prices

- high marginal costs
- costs not passed on (nominal rigidities)
- depresses markups $\Rightarrow$ redistribute to high MPC hh
- aggregate demand rises unless monetary policy curbs domestic demand enough
- production rises and this requires energy
- energy price responds to demand conditions

validated.

Energy-price-economic-activity feedback loop – open economy

Suppose non-fundamental beliefs of high energy prices with Foreign ownership

- high marginal costs
- costs not passed on (nominal rigidities)
- depresses markups $\Rightarrow$ redistribute to high MPC hh in Home
- and redistribute to Foreign (lower markups and high energy price)
- external demand linked to terms of trade: higher external demand (MPC of Foreign)
- aggregate demand rises unless monetary policy curbs domestic demand enough
- production rises and this requires energy
- energy price responds to demand conditions

validated.

Heterogeneity and fiscal support

Income redistribution:

- labor supply needs to rise, wages rise
- supports demand by hand-to-mouth households

Energy in consumption, not only production:

- counteracts rising wages for effective incomes
- makes energy supply to firms more elastic

Subsidies to energy:

- dampen reduction in demand
- support energy price further

Implications for monetary policy

- respond to energy price <u>even though energy price flexible</u>
- energy price matters for demand

- stronger response to consumer-price inflation
- core CPI inflation: $\phi_\Pi > 23.84$, headline CPI inflation: $\phi_\Pi > 2.66$

- target input price inflation (lean against wage and energy price): $\phi_\Pi > 1$

Related literature

- literature on energy and the macroeconomy
  - e.g. Blanchard and Galí, 2009; Blanchard and Riggi, 2013; Datta et al., 2021; Känzig, 2022; Nakov and Pescatori, 2009; Olivi et al., 2022 and many others
  - contribution: scarce energy supply can generate self-fulfilling loops
- literature questioning the Taylor principle
  - e.g. Ascari and Ropele, 2009; Bilbiie, 2008; Branch and McGough, 2009; Galí et al., 2004; Holden, 2022 and many others
  - contribution: novel mechanism through imported energy shortages
- literature on optimal monetary policy and shocks
  - e.g. Airaudo and Zanna, 2012; Aoki, 2001; Bodenstein et al., 2008; Carlstrom et al., 2006; Eusepi et al., 2011; Rubbo, 2022 and many others
  - contribution (i): choice of price index matters for determinacy
  - contribution (ii): better not “see through shocks”

Model

Households

- maximize lifetime utility $\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{C_{i,t}^{1-\sigma}}{1-\sigma} - \chi \frac{N_{i,t}^{1+\varphi}}{1+\varphi} \right] \right\}$
- hours worked, $N_{i,t}$
- consumption aggregator $C_{i,t} = \left[\gamma^{\frac{1}{\eta}} \left(C_{i,E,t} - \bar{e} \right)^{\frac{\eta-1}{\eta}} + (1-\gamma)^{\frac{1}{\eta}} C_{i,G,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$
  - γ: share of energy in consumption
  - η: willingness to substitute goods and energy
  - $\bar{e}$: subsistence level of energy energy consumption

Budget constraints

Details

Exposition here assumes all energy is owned by Foreign.

Savers:

$$\frac{B_t}{1-\lambda} + P_{E,t}C_{S,E,t} + P_{G,t}C_{S,G,t} \quad = \quad W_t N_{S,t} + \frac{P_t(D_t - T_t)}{1-\lambda} + \frac{s}{1-\lambda} B_{t-1} R_{t-1}$$

- share $1-\lambda$ of savers, stay saver with probability s
- own firms
- pay all taxes
- risk-free nominal bond B_t, at nominal return R_t

Hand-to-mouth households:

$$P_{E,t}C_{H,E,t} + P_{G,t}C_{H,G,t} \quad = \quad W_t N_{H,t} + \frac{1-s}{\lambda} B_{t-1} R_{t-1}$$

Households – optimality conditions

- consumption allocation

$$C_{i,E,t} - \bar{e} = \gamma \left(\frac{P_{E,t}}{P_t} \right)^{-\eta} C_{i,t} \qquad \text{and} \qquad C_{i,G,t} = (1-\gamma) \left(\frac{P_{G,t}}{P_t} \right)^{-\eta} C_{i,t}$$

- labor supply decision: $W_t / P_t = \chi C_{i,t}^{\sigma} N_{i,t}^{\varphi}$

- savers' intertemporal consumption decision:

$$C_{S,t}^{-\sigma} = \mathbb{E}_t \left[\beta \left(s C_{S,t+1}^{-\sigma} + (1-s) C_{H,t+1}^{-\sigma} \right) \frac{R_t}{\Pi_{t+1}} \right]$$

Firms

Details

- differentiated goods, demand elasticity $\varepsilon > 1$
- production function: $Y_{G,t} = \left[\alpha E_t^{\frac{\theta-1}{\theta}} + (1-\alpha) N_t^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$
  - α: share of energy
  - θ: elasticity of substitution between energy and labor
- quadratic price adjustment costs
- standard NK Phillips curve

Monetary and fiscal policy

Fiscal policy

- balanced budget
- households and firms pay $P_{E,t}$ for energy, Foreign receives $\widetilde{P}_{E,t}$
- energy subsidy if $\widetilde{P}_{E,t} > \widetilde{P}_E$
- taxes fall on saver households.

Monetary policy

- $R_t/R = (\Pi_{G,t})^{\phi_\Pi}$

Foreign

- supplies energy
- energy in fixed supply, ξ_E
- energy price $P_{E,t}$ determined by market clearing in Home

- imports Home goods

- budget

$$-B_t = \widetilde{P}_{E,t}\xi_E - P_{G,t}X_{G,t} + R_{t-1}(-B_{t-1})$$

- can accumulate net foreign assets $(-B_t)$

Foreign demand

- parameterize Foreign's demand for Home goods

$$\frac{X_{G,t}}{X_G} = \left(\frac{Y_t^*}{Y^*}\right)^{\mu_1} \times \exp\left(-\mu_2 \frac{B_{t-1}/P_{t-1}}{Y^*}\right)$$

- Foreign's energy revenues, in real terms: $Y_t^* = \widetilde{P}_{E,t}/P_{G,t} \times \xi_E$

- μ_1: Foreign's marginal propensity to demand exports out of energy revenues
- μ_2: Foreign's marginal propensity to consume out of savings

Market clearing

- bonds: domestic savings equal foreign debt
- labor: $N_t = \lambda N_{H,t} + (1-\lambda) N_{S,t}$
- energy: $\xi_E = \lambda\, C_{H,E,t} + (1-\lambda)\, C_{S,E,t} + E_t$
- goods: $Y_{G,t} = \lambda\, C_{H,G,t} + (1-\lambda)\, C_{S,G,t} + X_{G,t}$
- GDP: $P_t\, \mathrm{GDP}_t = P_{G,t} C_{G,t} + \widetilde{P}_{E,t} C_{E,t} + P_{G,t} X_{G,t} - \widetilde{P}_{E,t} \xi_E$

Paper-and-pencil intuition

Simplifying assumptions for now

- representative household (saver)
- energy is used in production only
- balanced trade
- share of energy in production equals elasticity of substitution
- $\beta \to 1$

Three-equation representation analogous to closed economy in Bilbiie (2008).

Threshold for determinacy

Taylor principle is violated (need $\phi_\Pi >> 1$ for determinacy)
if and only if

$$\frac{1}{2}\frac{\epsilon/\psi}{\sigma}\frac{1-\alpha}{\alpha} < 1,$$

that is, if

- Phillips curve sufficiently flat (low ϵ/ψ),
- households sufficiently unwilling to substitute intertemporally (high σ),
- energy inputs sufficiently important factor in production (high α).

Calibration of full model

Calibration strategy for energy

- so far, all energy is imported $\rightarrow$ match expenditure shares for imported energy
- energy that is in fixed supply $\rightarrow$ short-term view for natural gas
- target share of energy expenditures for Russian energy in Germany

Energy-related parameters

Details

Households

	impose symmetry in steady state
$\bar{e}$	subsistence; ∼25% of HH energy cons., Fried et al. (2022)
γ	share of energy in cons.; 1% expenditure share, Bachmann et al. (2022)
η	elasticity of substitution energy/goods of 0.1; Bachmann et al. (2022)

Firms

α	production share of energy: 5% cost share, Bachmann et al. (2022)
θ	elasticity of substitution energy/labor of 0.04; lower end of range in literature

Energy supply

μ_1	Foreign's MPC out of energy revenues of 0.5,
	think of emerging market with impatient government or sanctions
μ_2	Foreign's MPC out of NFA in long run, set to stabilize NFA, $\mu_2 = 0.02$

Important non-energy parameters

Details

- nominal rigidities ψ to match slope of paper-and-pencil Phillips curve of 0.05
- Frisch elasticity of labor supply of $1/\varphi = 1/2$
- share of spenders of $\lambda = 0.22$
- elasticity of intertemporal substitution of $1/\sigma = 1/3$
- monetary policy responds to core inflation with $\phi_\Pi = 1.5$

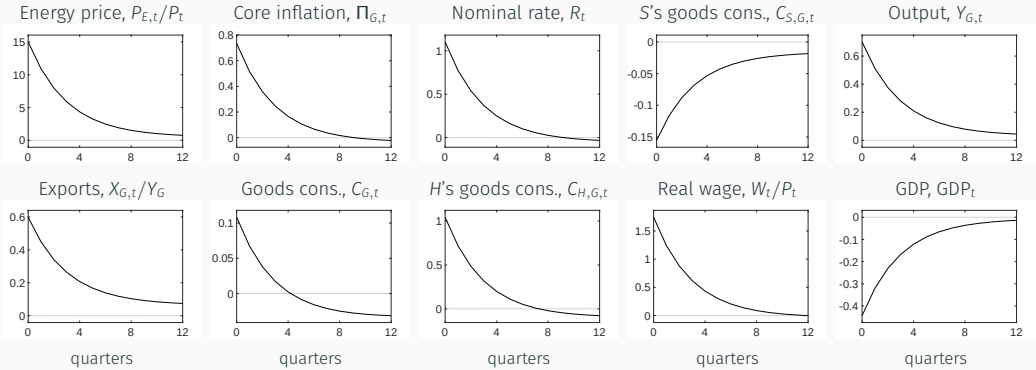
Quantitative results

Impulse response to sunspot shock

- indeterminacy
- exactly one explosive root missing
- elicit mechanism via impulse responses
- sunspot shock that causes an energy-price increase
- computed following the methodology of Bianchi and Nicolò (2021)

Impulse response to sunspot shock

Fundamental



- 20% sunspot increase in energy import prices → marginal costs and core inflation increase
- CB increases interest rate → savers' consumption falls
- but aggregate demand does not (foreign demand & hand-to-mouths' demand)
- output rises, GDP falls

Determinacy may require *not* to look through energy price movements

Definitions

targeting consumer price inflation

- core inflation: determinacy if $\phi_\Pi > 23.84$
- headline CPI: determinacy if $\phi_\Pi > 2.66$

some alternatives

- input-price inflation: determinacy if $\phi_\Pi > 1.0$
- or respond to energy price itself sufficiently strongly

Determinacy for alternative parameterizations of Taylor rule

$$R_t = \phi_\Pi \Pi_{G,t}, \ \phi_\Pi \geq 0$$

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- with abundant energy supply, determinacy for $\phi_\Pi > 1.39$

Determinacy for alternative parameterizations of Taylor rule

$$R_t = \phi_\Pi \Pi_{G,t}, \ \phi_\Pi \geq 0$$

- with abundant energy supply, determinacy for $\phi_\Pi > 1.39$
- with scarce energy supply, local determinacy for $\phi_\Pi >> 1$

Determinacy with dovish policy

$$R_t = \phi_\Pi \Pi_{G,t}, \ \phi_\Pi \geq 0$$

- ... or for ... $\phi_\Pi < 0.98$
- dovish, seemingly passive, policy rules out feedback loop as well

Energy-price-activity feedback loop: the role of Foreign

- higher energy price affects distribution of disposable income
  - from high- to lower-MPC households (energy in consumption)
  - from low-MPC to higher-MPC agents (energy in production)

- how important is the open-economy dimension?

Energy-price-activity feedback loop: closed economy

- consider: closed economy, permanent Htm and savers
- otherwise same pencil-and-paper assumptions as before
- heterogeneous households: Taylor principle more likely to break if HTM consumption sufficiently procyclical

Energy-price-activity feedback loop: closed economy

- can show that $\widehat{C}_{H,t} = \Gamma_{CH}\widehat{Y}_t$, with

$$\Gamma_{CH} = 1 + \varphi + \frac{\varphi}{1-\alpha}\frac{(\alpha\tau^e - \tau^d)}{\lambda} + \frac{\varphi\alpha}{\theta(1-\alpha)(\varphi + (1-\alpha)\sigma)}\frac{(\tau^e - \tau^d)}{\lambda}$$

τ^e, τ^d: share of Htm households in energy revenues and firm profits

- energy revenues: Htm consumption more procyclical
- share in profits: less procyclical

Conclusions

Conclusions

environment with inelastic supply of an imported good

- external demand positively linked to price of imported good
- domestic absorption less interest sensitive due to subsidies and heterogeneity

monetary policy prevents self-fulfilling energy-price-economic-activity loop if

- *hawkish*[2]: strong focus on headline inflation, focus on input prices; even in recession
- *dovish*[2] : violate Taylor principle

if one price is directly demand-relevant, choice of price index matters

Appendix

Appendix: Model: Households – two types with idiosyncratic risk

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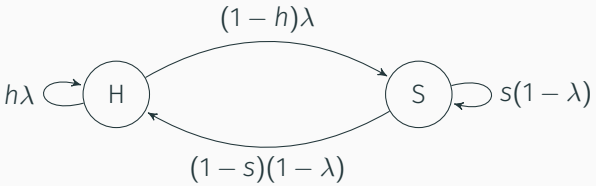
- hand-to-mouth (or spenders), H; share in population λ
- savers, S: share in population $1 - \lambda$
- idiosyncratic risk determined by probabilities h and s

Figure 1: Flows across islands between period t and $t + 1$



Appendix: Model: Households – further household equations

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- marginal price index: $P_t = \left[\gamma P_{E,t}^{1-\eta} + (1-\gamma) P_{G,t}^{1-\eta}\right]^{\frac{1}{1-\eta}}$

Appendix: Model: Firms – retailer's problem

- unit mass of producers of differentiated goods, indexed by $j \in [0, 1]$
- retailer assembles differentiated goods into consumption good
- retailer's production function: $Y_{G,t} = \left[\int_0^1 y_{G,t}(j)^{\frac{\varepsilon-1}{\varepsilon}} dj\right]^{\frac{\varepsilon}{\varepsilon-1}}$
- retailer's demand function: $y_{G,t}(j) = \left(\frac{P_{G,t}(j)}{P_{G,t}}\right)^{-\varepsilon} Y_{G,t}$
- producer-price index: $P_{G,t} = \left[\int_0^1 P_{G,t}(j)^{1-\varepsilon} dj\right]^{1/(1-\varepsilon)}$

Appendix: Model: Firms – intermediate firms' problem

- differentiated good, $y_{G,t}(j)$ is produced using labor, $N_t(j)$, and energy, $E_t(j)$:

$$y_{G,t}(j) = \left[\alpha E_t(j)^{\frac{\theta-1}{\theta}} + (1-\alpha)N_t(j)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}$$

- each firm sets its price subject to retailer's demand, its production function, and price adjustment costs, by maximizing profits:

$$\mathbb{E}_t\left\{\sum_{k=0}^{\infty}\mathcal{F}_{t,t+k}\frac{1}{P_{t+k}}\left[P_{G,t+k}(j)(1+\tau^y)y_{G,t+k}(j) - W_{t+k}N_{t+k}(j)\right.\right.$$
$$\left.\left.-P_{E,t+k}E_{t+k}(j) - \frac{\psi}{2}P_{G,t+k}Y_{G,t+k}\left(\frac{P_{G,t+k}(j)}{P_{G,t+k-1}(j)} - 1\right)^2\right]\right\}$$

Appendix: Model: Firms – symmetric equilibrium

- firms' real profits, with sales subsidy:

$$D_t = (1+\tau^y)\frac{P_{G,t}}{P_t}Y_{G,t} - \frac{W_t}{P_t}N_t - \frac{P_{E,t}}{P_t}E_t - \frac{\psi}{2}\frac{P_{G,t}}{P_t}Y_{G,t}\left(\Pi_{G,t}-1\right)^2$$

- non-linear PPI Phillips curve with savers' stochastic discount factor for profits

$$\psi\Pi_{G,t}(\Pi_{G,t}-1) = (1+\tau^y)(1-\varepsilon) + \varepsilon\Lambda_t\left(\frac{P_{G,t}}{P_t}\right)^{-1} + \psi\mathbb{E}_t\left[\mathcal{F}_{t,t+1}\Pi_{G,t+1}(\Pi_{G,t+1}-1)\frac{Y_{G,t+1}}{Y_{G,t}}\frac{P_{G,t+1}/P_{t+1}}{P_{G,t}/P_t}\right]$$

- optimal factor input shares: $W_t/P_{E,t} = \frac{1-\alpha}{\alpha}\left(E_t/N_t\right)^{1/\theta}$
- real marginal costs: $\Lambda_t = \left[\alpha^\theta\left(P_{E,t}/P_t\right)^{1-\theta} + (1-\alpha)^\theta\left(W_t/P_t\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}$

Appendix: Model: Monetary and fiscal policy – inflation indices

Back

input-price inflation:

$$\Pi_{\text{nmc,t}} = \frac{\left[\alpha^{\theta} P_{E,t}^{1-\theta} + (1-\alpha)^{\theta} W_t^{1-\theta}\right]^{\frac{1}{1-\theta}}}{\left[\alpha^{\theta} P_{E,t-1}^{1-\theta} + (1-\alpha)^{\theta} W_{t-1}^{1-\theta}\right]^{\frac{1}{1-\theta}}}$$

Appendix: Paper-and-pencil intuition – three-equation representation

Back

- Dynamic IS curve:

$$\widehat{Y}_{G,t} = \mathbb{E}_t \widehat{Y}_{G,t+1} - \frac{1}{\widetilde{\sigma}} \left[\widehat{R}_t - \mathbb{E}_t \widehat{\Pi}_{G,t+1} \right] \quad \text{with} \quad \widetilde{\sigma} := \frac{\sigma}{1-\alpha} \frac{1-\alpha\left[1+\varphi+\frac{1}{\theta}\right]}{1-\alpha+\alpha\sigma}$$

- New Keynesian Phillips curve:

$$\widehat{\Pi}_{G,t} = \beta \mathbb{E}_t \widehat{\Pi}_{G,t+1} + \widetilde{\kappa}\, \widehat{Y}_{G,t} \quad \text{with} \quad \widetilde{\kappa} := \frac{\epsilon}{\psi} \frac{\sigma+\varphi+\frac{\alpha}{\theta}(1-\sigma)}{1-\alpha+\sigma\alpha}$$

- Taylor rule:

$$\widehat{R}_t = \phi_\Pi \widehat{\Pi}_{G,t} \quad \text{with } \phi_\Pi \geq 0$$

Appendix: Paper-and-pencil intuition – sign of $\widetilde{\kappa}$

Back

$$\text{sgn}\,\widetilde{\kappa} = \text{sgn}\,\frac{\epsilon}{\psi}\,\frac{\sigma+\varphi+\frac{\alpha}{\theta}(1-\sigma)}{1-\alpha+\sigma\alpha} = \text{sgn}\left(\sigma+\varphi+\frac{\alpha}{\theta}(1-\sigma)\right)$$

- $\frac{\sigma+\varphi+\frac{\alpha}{\theta}(1-\sigma)}{1-\alpha+\sigma\alpha}$ is the elasticity of marginal costs with respect to output
- $\sigma+\varphi$ is standard wealth effect and effect of compensation for disutility of work on wages, would capture entire effect if wages and energy prices move in lock-step
- $\frac{\alpha}{\theta}(1-\sigma)$ captures the excess effect of energy prices on marginal costs, matters if (i) large energy share in production, α, or (ii) little substitutability, $1/\theta$
- $1-\sigma$ captures two countervailing effects of excess sensitivity:
  - direct effect: higher output comes with higher marginal costs
  - indirect effect: given output, a rise in energy prices reduces households' consumption (a larger share of output is consumed by foreign), wealth effect reduces wages and thus marginal costs (wealth effect increases in σ)
- if $\frac{\alpha}{\theta}(1-\sigma)$ is negative and large in absolute value, $\widetilde{\kappa}$ inverts

Appendix: Paper-and-pencil intuition – sign of $\widetilde{\sigma}$

Back

$$\text{sgn}\,\widetilde{\sigma} = \text{sgn}\,\frac{\sigma}{1-\alpha}\frac{1-\alpha\left[1+\varphi+\frac{1}{\theta}\right]}{1-\alpha+\alpha\sigma} = \text{sgn}\left(1-\alpha\left[1+\varphi+\frac{1}{\theta}\right]\right)$$

- $1-\alpha\left[1+\varphi+\frac{1}{\theta}\right]$ reflects the comovement of aggregate consumption with output
- α measures the share of energy in production and thus the share of output exported
- with constant energy prices and linear production, $1-\alpha$ would capture all effects
- $\left[1+\varphi+\frac{1}{\theta}\right]$ captures disproportionate movements with output in input prices, if energy prices would move one-to-one with wages, $1+\varphi$ would capture all effects; $1/\theta$ measures (again) the excess sensitivity of energy prices to output
- $\widetilde{\sigma}$ inverts if energy is important (α), labor supply is inelastic (φ), or energy is hard to substitute ($1/\theta$)

Appendix: Paper-and-pencil intuition – signs of $\widetilde{\sigma}$ and $\widetilde{\kappa}$

Back

$$\operatorname{sgn}\widetilde{\sigma} = \operatorname{sgn}\left(1-\alpha\left[1+\varphi+\frac{1}{\theta}\right]\right) \quad\Longrightarrow\quad \widetilde{\sigma}>0 \quad\longleftrightarrow\quad 1-\frac{\alpha}{\theta}>\alpha(1+\varphi)$$

$$\operatorname{sgn}\widetilde{\kappa} = \operatorname{sgn}\left(\sigma+\varphi+\frac{\alpha}{\theta}(1-\sigma)\right) \quad\Longrightarrow\quad \widetilde{\kappa}>0 \quad\longleftrightarrow\quad 1-\frac{\alpha}{\theta}>-\frac{1}{\sigma}\left(\varphi+\frac{\alpha}{\theta}\right)$$

- $\alpha(1+\varphi)>0$ and $-\frac{1}{\sigma}\left(\varphi+\frac{\alpha}{\theta}\right)<0$
- hence, whenever $\widetilde{\sigma}>0$, also $\widetilde{\kappa}>0$
- for $\widetilde{\sigma}<0$, we can still have either $\widetilde{\kappa}>0$ or $\widetilde{\kappa}<0$

Appendix: Paper-and-pencil intuition – corollary

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Corollary: Insufficiency of Taylor principle

Consider the same conditions as above. Suppose further that $\alpha = \theta$, that is, that the weight of energy in production equals the elasticity of substitution between energy and labor. Then the lower bound on ϕ_Π that ensures indeterminacy will be higher than suggested by the Taylor principle if and only if

$$1 > \frac{1}{2} \frac{\epsilon/\psi}{\sigma} \frac{1-\alpha}{\alpha},$$

that is, if the Phillips curve absent energy-price feedback is sufficiently flat (low ϵ/ψ), if households are sufficiently unwilling to substitute intertemporally (high σ), and if energy inputs are a sufficiently important cost factor in production (high α).

Appendix: Calibration – other parameters

Back

Households	
β	discount factor; 2% real rate of interest
σ	inverse of IES; realistic IES of consumption of 1/3
χ	disutility of labour supply; normalize labor supply to unity; implies 0.8998
φ	Frisch elasticity of labor supply of 1/2; in line with range in literature
λ	share of hand-to-mouth households of 0.22; estimates by Slacalek et al. (2020)
s	probability of staying unconstrained of 0.98; Bilbiie et al. (2022)
Firms	
ε	elasticity of substitution varieties; conventional 10% markup
ψ	price adjustment costs; match 0.05 slope of NKPC, implies 500
Energy supply	
μ_2	Foreign's MPC out of savings of 0.02, stabilize net foreign assets
Government	
τ^y	production subsidy; no markup in steady state
τ^d	no profit redistribution; savers receive profits and pay all taxes
ϕ_Π	response to inflation of 1.5; standard value

Appendix: Calibration – how to think about Foreign's MPC?

Back

- energy exporter is an emerging-market economy w/o sovereign wealth fund
- facts to keep in mind:
  - emerging-market economies have higher MPCs
  - financial trade with Russia, but also other energy exporters, is limited due to sanctions, implying a relatively higher MPC (closer to instant settlement)
  - current situation: are Russians in the middle of a severe crisis likely to save or spend?
  - MPC also governs the behavior of debt relative to the trade volume, how much would a country borrow to another country (in percent of trade volume)?
  - MPC out of energy revenues is likely to be higher than "normal" MPC (e.g. due to pro-cyclicality of government spending in energy exporting countries)!

Appendix: Calibration – symmetric across households

Back

Variable	Value	Description	Variable	Value	Description
Households			Prices		
C	1.0556	Consumption	$\Pi_G = \Pi$	1	Inflation
C_E	0.19	Energy cons.	P_E/P	0.055705	Real energy price
C_G	0.9405	Goods cons.	P_G/P	1.1141	Real goods price
N	1	Labor supply	W/P	1.0584	Real wage
Production			R	1.005	Gross nom. rate
Y_G	1	Output			
E	1	Energy in prod.			
D	0.11141	Profits			
Λ	1.1141	Real marginal costs			

Households' energy expenditure share & firms' energy expenditure share as targeted, economy-wide expenditure on energy over value of output is 5.95%.

Appendix: Quantitative results – methodology

Back

- Bianchi and Nicolò (2021): approach to deal with indeterminacy in LRE models
  - augment original state space with a set of auxiliary exogenous equations to achieve the adequate number of explosive roots
  - the solution in the expanded state space is always determinate and identical to the indeterminate solution in the original state space
  - selection of equilibrium based on zero restriction: set correlation of the fundamental disturbances with the sunspot shocks to zero

- other approaches select other equilibrium but span the same set of equilibria
  - e.g. Lubik and Schorfheide (2004) minimize distance between IRFs of indeterminate and determinate solution at boundary of determinacy region
  - irrelevant for determinacy threshold, only matters for the precise shape of the IRFs which we just use to illustrate the mechanism that causes the indeterminacy

Appendix: Quantitative results – methodology

Back

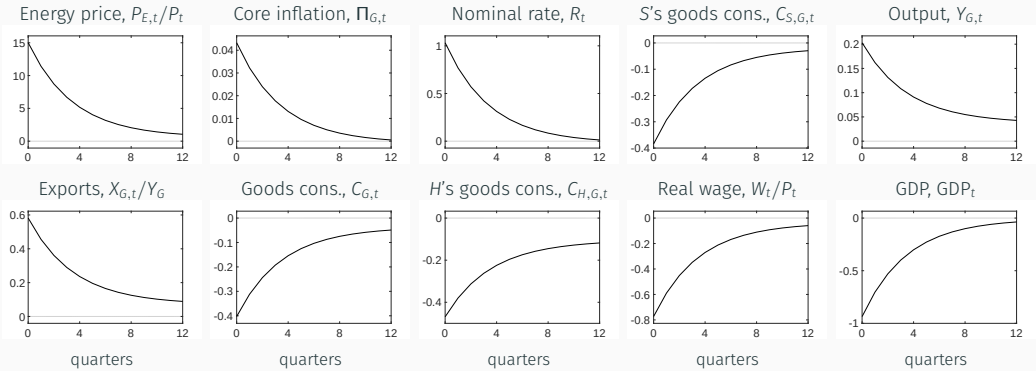
our case: up to one degree of indeterminacy $\rightarrow$ add one auxiliary equation and sunspot shock $\varepsilon_{\omega,t}$, linking (any) forecast error to the sunspot shock, for instance,

$$\log \omega_t = \rho_\omega \log \omega_{t-1} + \varepsilon_{\omega,t} + \Big(\log C_t - \mathbb{E}_{t-1} [\log C_t] \Big)$$

- determinate model: choose $\rho_\omega < 1$, equation is irrelevant
  - sunspot does not affect equilibrium, just drives ω_t which does not enter the economy
- indeterminate model: $\rho_\omega > 1$, one additional explosive root
  - sunspot affects equilibrium, ω_t must be zero, hence, sunspot shifts forecast error thereby affecting agents decisions, for instance, consumption is non-fundamentally higher than expected (variable does not matter here)

IRFs: fundamental energy price increase under hawkish policy

Sunspot



Percentage dev. from st. st., except exports (percent of st. st. output). Interest & inflation rates are in ann. pp.; $\phi_\Pi = 23.84$, core inflation.

- 20% fundam. increase in energy import prices → marginal costs and core inflation increase
- CB increases interest rates a lot → savers' consumption falls much more
- effect of heterogeneity muted because real wage falls

Appendix: Quantitative results – sensitivity analyses

- model features
  - Foreign's MPC: essential for feedback loop, higher foreign demand kick-starts the feedback loop, baseline is determinate for $\mu_1 \leq 0.3$
  - household heterogeneity: crucial at baseline (foreign demand kick-starts, Keynesian multiplier fuels), for $\mu_1 \geq 0.7$, even for rep. agent model not determinate
  - elasticity of energy supply: weakens (but not necessarily overturns) the results, for small elasticities, Taylor principle still insufficient
  - domestic ownership of energy supply: standard determinacy regions, feedback loop is initialized by foreign demand

- (some) parameter choices
  - firms' energy dependence strengthens results, households' weakens
  - energy demand elasticity weakens results, subsistence strengthens
  - intertemporal elasticity of substitution weakens results
  - labor supply elasticity weakens results

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